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CALIBRATION OF RADIATION INSTRUMENTATION IN A RADON/THORON TEST FACILITY OF THE WALK-IN TYPE

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by

J. Bigu*

ABSTRACT

A number (55) of radon and radon progeny instruments have been tested and calibrated in a Radon/Thoron Test Facility (RTTF) of the walk-in type. The calibration included instruments of the passive as well as the active type. Measurements were preferentially conducted under conditions of low aerosol concentration (0.5×10^3 - 3.5×10^3 cm^{-3}) and low relative humidity ($\lesssim 70\%$). The radon gas concentration was maintained at about 45 pCi/L $\pm$ 4.5 pCi/L. The radon progeny Working Level was chosen to vary from about 20 mWL to 95 mWL by varying the aerosl concentration and/or the relative humidity. The performance of the instruments rated from poor to very good depending on the type of instrument. This work was requested by Atomic Energy of Canada Limited (AECL) for a monitoring and remedial action program in some Elliot Lake dwellings.

Keywords: Radon instrumentation; Radon progeny instrumentation; Calibration; Radiation.

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ÉTALONNAGE DE L'APPAREILLAGE DE RAYONNEMENT DANS UNE GRANDE INSTALLATION EXPÉRIMENTALE, MODÈLE PLEIN-PIED, UTILISÉE POUR DES ESSAIS SUR LE RADON ET LE THORON

par

J. Bigu*

RÉSUMÉ

On a étudié et étalonné un certain nombre d'appareils (55) de radon et de produits de filiation du radon dans une grande installation expérimentale (IERT), modèle plein-pied, utilisée pour des essais sur le radon et le thoron. Des appareils de types passif et radioactif ont fait l'objet de l'étalonnage. Les mesures ont été effectuées de préférence dans des conditions de faible concentration d'aérosols ($0{,}5 \times 10^3$ - $3{,}5 \times 10^3$ cm^{-3}) et d'humidité relative basse (≤ 70 %). Les concentrations du radon ont été maintenues à environ 45 pCi/L ± 4,5 pCi/L. Le niveau de travail "Working Level" des produits de filiation du radon a été choisi afin de varier entre 20 mWL environ et 95 mWL en variant la concentration d'aérosols et d'humidité relative ou seulement la concentration d'humidité relative. On a classé le rendement des appareils de pauvre à très bon selon le genre d'appareil. Énergie Atomique du Canada Limitée (EACL) nous a demandé d'effectuer cette étude dans le cadre d'un programme de surveillance et d'action corrective dans certaines résidences d'Elliot Lake.

Mots-clés: Appareillage de radon; Appareillage de produits de filiation du radon; Étalonnage; Rayonnement.

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INTRODUCTION

It is generally recognized that inhalation of radon progeny results in the largest single contribution to the average effective dose equivalent received by members of the public (1). Monitoring of radon progeny is, therefore, of utmost importance in order to assess potential radiation health hazards associated with occupational workers and the general public alike.

The accuracy with which radon and its progeny can be measured depends to a great extent on the type of instrument, and technique and method used. Hence, calibration of radiation instrumentation in reference radioactivity atmospheres cannot be emphasized enough.

Radon and its progeny can be measured by means of a variety of commercially available instruments of the passive and active type, using techniques which range from grab-sampling to time-integrating and continuous monitoring, employing a variety of radioactivity counting methods.

This report presents data on a technical evaluation and calibration of several radon and radon progeny instruments of the passive and active type. It includes results on a personal dosimeter of the active type, several radon gas monitors of the passive and active type, and a number of radon progeny environmental monitors (e.g., Working Level monitors) of the active kind. A total of 55 instruments were tested.

The evaluation of the above instrumentation was carried out in a Radon/Thoron Test Facility (RTTF) of the walk-in type (2). Tests were conducted in radon/radon progeny atmospheres.

The evaluation of the instrumentation subject of this report was requested by Atomic Energy of Canada Limited (AECL) for a monitoring and remedial action program in some Elliot Lake dwellings (3). A technical evaluation of other instrumentation used for the same purpose has been

published elsewhere (4-6).

Instrumentation for the monitoring and remedial action program was sent to the Elliot Lake Laboratory (CANMET, Energy, Mines and Resources Canada) by several organizations, such as Atomic Energy Control Board (AECB), Radiological Protection Bureau (RPB), National Health and Welfare, the Ontario Ministry of Labour (MOL), and AECL. In addition, instrumentation from the Elliot Lake Laboratory was also concurrently evaluated.

The data presented here were obtained during March 1985. Data collected in a later technical evaluation, using other types of instrumentation, during June-September 1985, have been reported elsewhere (4-6).

DESCRIPTION OF THE INSTRUMENTATION TESTED

The instruments tested have been described in the literature. For this reason only brief comments on their operating procedure will be indicated. For simplicity, the instrumentation will be divided into three categories, namely: personal dosimeters for radon progeny, Working Level monitors, and radon gas monitors.

A. RADON GAS MONITORS

Five different radon gas monitors of the passive type were evaluated:

a) The PRIM, a passive radon gas monitor that uses thermoluminescent chips (TLD) as particle detectors. Radon progeny from air is removed by means of polyurethene 'foam' before entering the 'sensitive volume' of the instrument. The collection efficiency of the radon progeny formed by decay of the freshly filtered radon in the sensitive volume is electrostatically enhanced. The sensitive volume consists of an electrostatically charged metal mesh cylinder at a positive electrical potential (1200 V) relative to a mylar sheet covering the TLD chips. The latter are mounted on the bottom side of the upper base of the

electrostatic collector. The instrument is commercially available from EDA Instruments (Toronto) under the commercial name RDT-322.

b) Terradex (U.S.A) track-etch environmental monitors. This type of monitor consists of a small plastic cup of a few cm^3 volume, the 'sensitive volume' of the monitor is separated from the outside environment by means of a radon-permeable plastic material. The radon progeny is filtered-out by the membrane material whereas radon diffuses through it into the sensitive volume where it decays into its progeny and is 'recorded' by the track-etch material.

c) National Radiation Protection Bureau (NRPB), U.K., radon monitors. These monitors are used by RPB (Canada) and are similar in design and operation principles to the Terradex monitors except that they use CR-39 as track-etch material.

d) The AB-5/EL and AB-5/PRD radon gas monitoring systems are manufactured by Pylon Electronics Development (Ottawa). They consist of a multipurpose, programmable, scaler: the AB-5, and a radon gas detector, one based on passive diffusion through a porous material, the passive radon gas detector model PRD, and the other, of the active kind, based on electrostatic deposition, model EL. Both systems can operate intermittently and on a continuous basis. The AB-5/EL and AB-5/PRD systems have been described in detail by the author elsewhere (5). Hence, no more details will be given.

B. PERSONAL DOSIMETER

One radon progeny dosimeter of the active type was evaluated:

a) The alpha-NUCLEAR personal dosimeter uses a diffused-junction silicon detector, and associated electronic circuitry. Sampling flow-rate is ~0.1 L/min. The dosimeter is programmable by means of a personal computer and an interface unit. The latter is mounted on the side of the dosimeter.

This dosimeter provides the user with time-profile Working Level, average WL and a variety of other useful data. The dosimeter can be mounted on a NiCd battery or a miner's cap lamp battery for ease of operation. This dosimeter is commercially available from alpha-NUCLEAR (Toronto) under the commercial name alpha-PRISM. Different software packages are available for different applications.

C. WORKING LEVEL (RADON PROGENY) MONITORS

Four different radon progeny monitors of the active type were tested:

a) The WLM-300 is manufactured by EDA Instruments (Toronto). This Working Level monitor uses a silicon-barrier detector and operates on α-particle time-integrating principles. The WLM-300 is designed to operate as a continuous monitor at a flow-rate of 1 L/min. The monitor provides total α-count, differential α-count, differential Working Level, and average Working Level over any period of time. Counting times can be chosen as 6 min or 60 min. The interested reader should consult reference (7) for more detailed information regarding this instrument;

b) The RGA-400 is also manufactured by EDA Instruments, and is an outgrowth of the WLM-300. The RGA-400 consists of a radon progeny monitor and a radon gas monitor packed in a single instrument. It uses silicon-barrier detectors as α-particle detectors with their associated electronic circuitries. The RGA-400 has α-spectrometric capabilities. The two detection systems are designed to operate in series, i.e., air passes through a filter facing a silicon-barrier detector where the radon progeny is counted. The exhaust from the radon progeny sampling head/detection system is then directed to an electrostatically enhanced detection system consisting of a 3 L cylinder with a silicon-barrier detector, located at the exhaust side of the chamber, where radon gas is counted. The instrument is fully programmable and operates at a flow-rate of 1 L/min.

The interested reader should consult reference (8) for more details.

d) The M.O.L. radon progeny monitors consist of a small sampling pump of the aquarium type (1-2 L/min) and a sampling head, attached to the pump, that uses a track-etch material (cellulose nitrate LR-115 type 2) as radon progeny detector. The track-etch detector faces the sampling filter as is common practice in radon progeny monitors.

e) The MOD-225 is a continuous radon progeny monitor that uses TLD chips as α-particle detectors. As is standard practice, when using TLD chips for α-particle detection, a shielded and an unshielded TLD chip are used in the same sampling head. The unshielded TLD chip responds to α-, β- and γ-radiation. Hence, if the responses from the two chips are subtracted from one another, the net α-particle contribution can be estimated. Sampling flow-rate is adjustable, but usually is factory set at about 2 L/min. The MOD-225 can use LiF, CaF_2:Dy or any other TLD material. In the present case LiF chips were employed. The MOD-225 is manufactured by EDA Instruments (Toronto).

f) The AB-5/AEP radon progeny monitoring system is manufactured by Pylon Electronic Development (Ottawa). The system consists of a multipurpose, programmable, scaler: the AB-5, and a radon progeny sampling head model AEP. The latter consists of a ZnS screen facing a Nuclepore filter (0.8 μm). The AEP is fitted to the front of the AB-5 with the ZnS screen facing a photomultiplier tube. The AB-5/AEP system can operate continuously and on an intermittent basis. The interested reader should refer to reference (4) for more details on this instrument.

EXPERIMENTAL PROCEDURE

Testing and calibration of instrumentation were conducted in a Radon/Thoron Test Facility of the walk-in type (2). The instruments were

tested under laboratory-controlled environmental conditions of temperature, relative humidity, aerosol concentration and radiation level (radon gas concentration and radon progeny concentration).

Tests were conducted during March 1985. The operating conditions of the RTTF during this period are shown in Table 1. Tests were preferentially conducted at low aerosol concentrations and low relative humidity. These conditions were chosen to study plate-out effects of radon progeny monitors operating on active principles.

Plate-out effects are known to occur preferentially at low aerosol concentrations, thereby leading to substantial errors in the estimation of the Working Level, WL. This effect is highly dependent on the mechanical design (geometry) of the sampling head. The case of low aerosol concentration is important in dwellings of non-smokers in cold countries where low relative humidity and low aerosol concentration compound plate-out phenomena.

High relative humidity/high aerosol concentration conditions are important to measure the effect of filter 'loading' in radon daughter instruments of the active kind. Filter loading leads to a decrease in the detector/sampling head counting efficiency. and hence, to an underestimation of WL. For instruments that use α-spectrometry principles, filter loading results in a broadening of the spectrum and a shift of the photopeaks to lower energies. These effects are caused by α-particle absorption and self-absorption effects in the filter material, partially caused by the deposition of aerosol and water vapour in the filter. The case of high aerosol concentration/high relative humidity is quite relevant in underground uranium mines where the above conditions prevail and can lead to large errors in the estimation of WL. Furthermore, the presence of high concentrations of corrosive aerosols and water vapour is known to affect the performance of electronic circuitry of radiation instruments.

Relative humidity and aerosol concentrations do not affect radon gas concentrations in the RTTF. However, air moisture content may affect the response of radon gas monitors operating on electrostatic collection principles. Extensive tests under conditions of high aerosol concentration and high relative humidity are reported elsewhere (4-6).

Experiments were conducted within a quite narrow range of values for the radon gas concentration, mostly ~45 pCi/L $\pm$ 5 pCi/L. Working Levels ranged from about 20 mWL to 95 mWL. The Working Level was changed by changing the aerosol concentration and/or varying the relative humidity in the RTTF.

Radon gas concentrations were maintained constant, within less than $\pm$10%, for extended periods, i.e., several weeks. The Working Level was maintained constant, within about $\pm$10%, for periods of 8 h to 24 h, depending on the test conducted. Rapid variations in WL were also introduced, whenever necessary, to investigate the response and performance of some instruments to transient conditions.

Radon/radon progeny atmospheres were produced by injecting radon gas, ^{222}Rn, into the RTTF by means of radon gas flow-through sources model Rn-1025 manufactured by Pylon Electronic Development (Ottawa).

Aerosol was generated using an atomizer model 3076 in conjunction with its associated air supply system, column desiccator, and electrical charge neutralizer, all manufactured by T.S.I (U.S.A). An aqueous solution of NaCl (0.001 - 1 g/L) was used to produce the aerosol cloud. Relative humidity was varied by means of conventional humidifiers.

Radon and aerosol were injected into the RTTF through injection ports located opposite the air exhaust system.

Radon gas concentration in the RTTF was continuously monitored by means of two radon gas continuous monitoring systems, namely: the RGM-2, a radon gas monitor manufactured by Eberline (U.S.A), and an in-house developed radon

gas monitoring system, the RM-1003/AIM-65 system (RM-1003, for short). The RGM-2 and RM-1003 systems provided radon concentration, [^{222}Rn], measurements every hour and 20 min, respectively. In addition, radon gas concentrations were periodically measured by grab-sampling, using the scintillation cell method, and by the two-filter method (9.10).

Radon daughter concentrations were measured by grab-sampling using the Thomas-Tsivoglou method, and the Kusnetz method (11.12). Radon daughter concentrations and WL by grab-sampling were measured every 40 min. A calibrated Working Level monitor, model WLM-300, manufactured by EDA, was also used to record the WL continuously, i.e., one measurement every hour.

Radon gas and radon daughter measurements were conducted at at least two different locations simultaneously in an area where radiation instruments to be calbrated were located. Results from different locations were taken and an average was calculated in each case.

Air temperature, relative humidity and barometric pressure were measured using a meteorological package manufactured by alpha-NUCLEAR (Toronto) consisting of a data logger model 650 in conjunction with air temperature, dew point, and barometric pressure probes models 602, DS001, and 604, respectively. Aerosol concentration was measured by drawing air samples continuously in a recirculation mode through two condensation nuclei counters, model RICH 200, manufactured by Environment One (U.S.A), and model 3020, manufactured by TSI (U.S.A).

Radiation instruments to be calibrated were placed in a large three-shelf metal mesh structure so designed as to produce minimum disturbance to the air flow in the RTTF. Several instruments were placed on each shelf. However, special care was taken to minimize mutual instrument interference or disturbance or air patterns by the instruments.

The readings of the instruments were compared with radon gas

concentration and/or Working Level measurements carried out by the standard (calibrated) instrumentation used for monitoring purposes.

Radon and radon progeny monitors, and radon progeny dosimeters, of the active and passive type were tested. The instruments operated on a continuous, or quasi-continuous, i.e., intermittent, fashion using either time-integrating techniques, followed by differential counting, or total α-count. Some instruments operated continuously, whereas others were meant to operate for an 8-hour period at a time. The radiation detection system of the instruments used ranged from electronic detectors, such as silicon-barrier (SiB), and diffused-junction (DJ) detectors, to thermoluminescent detectors (TLD), track-etch film detectors, and scintillation cells, with and without electrostatic collection enhancement. A total of 55 instruments were tested and calibrated.

EXPERIMENTAL RESULTS AND DISCUSSION

The operating conditions of the RTTF are shown in Table 1. The Table shows that the range of values for the different values of interest was as follows:

a) Temperature (T): 19-23^{o}C

b) Relative humidity (RH): 50-70%

c) Aerosol concentration (N): 0.5×10^{3} - 3.3×10^{3} cm^{-3}

d) Radon Working Level (WL): 20-95 mWL

e) Radon gas concentration [^{222}Rn]: ~45 pCi/L $\pm$ 10%

f) Equilibrium factor (F): 0.05-0.22

g) [^{214}Pb]/[^{218}Po]: 0.11-0.39

h) [^{214}Bi]/[^{218}Po]: 0.07-0.30

As indicated previously, and shown above, and in Table 1, the conditions chosen for the RTTF were low aerosol concentration and low relative

humidity. These conditions resulted in low radon progeny concentrations, disequilibrium ratios (DR) and equilibrium factors (F). The results of the instruments evaluation are given in Tables 2 to 12. It should be noted that square brackets are used here to indicate activity concentration (pCI/L).

Table 2 shows data obtained with 11 PRIMS. All units used LiF as TLD material. The instruments had been calibrated previously at AECB. The sensitivity calculated, and the corresponding $[^{222}Rn]$, obtained from calibration best-fitted graphs, are indicated in columns 5, 6 and 7 of Table 2, respectively. Because of the large size of the instruments, and the fact that concurrent measurements on many other monitors were being done, some of the PRIMS were located on the floor of the RTTF, and some others were placed on top of one another. The instruments were located at the exhaust side of the RTTF. For lack of more direct data, the $[^{222}Rn]_{RTTF}$ given in Table 2, measured at several locations in the RTTF, are assumed to apply to this particular situation. Table 2 shows that, in general, the PRIMs underestimated the radon gas concentration. The average calibration factor (CF), defined by $CF = (PRIM)_o/[^{222}Rn]_{RTTF}$ was 0.79 ± 0.20.

Table 3 shows data obtained with six PRIMs using CaF_2:Dy as TLD material. The table shows that the average CF was substantially greater than 1, i.e., CF = 1.64. In other words, these PRIMs significantly overestimated the radon gas concentration. The location these PRIMs were assigned is similar to that for the PRIMs discussed in Table 2.

Table 4 gives data for the ten NRPB radon gas monitors tested. For both exposures the calibration factor, CF, was significantly greater than 1, i.e., $CF = 1.42 \pm 0.27$ (March 19-24), and $CF = 1.32 \pm 0.11$ (March 19-29). The possibility of air leaks to account for these large values should not be ruled out.

Table 5 shows data for 10 Terradex track-etch radon gas monitors. The

agreement with the radon gas concentration measured in the RTTF was found be be fair to good, and significantly better than for the NRPB radon gas monitors. In this case, however, the Terradex detectors slightly underestimated, on the average, the radon gas concentration.

Table 6 shows data corresponding to three radon gas continuous monitoring systems. The agreement with values for the RTTF can be considered fair to poor. Other arrangements or combinations consisting of different AB-5 and PRD or EL detectors were tried but malfunctioned. The results are not included in this report.

Table 7 shows the performance of three α-particle personal dosimeters by alpha-NUCLEAR. When the instruments operated, the agreement with RTTF data was fair to good with a tendency to underestimate the Working Level. However, as the table shows, there were frequent malfunctions that made analysis of the data difficult. Instrument No. 009 never operated satisfactorily, whereas No. 010 failed three times out of five. Only unit No. 056 operated at all times.

Table 8 gives the sensitivity, nC/WLH, of six MOD-255 exposed in the RTTF during two periods or exposure times. The overall average sensitivity calculated from these data is 2.17 ± 0.35 nC/WLH.

Table 9 shows the response of three AB-5/AEP continuous Working Level monitoring systems. The performance of the three instruments according to their CF = WL_{AB-5}/WL is rated from poor (AB-5 No. 202 with AEP-25 No. 106) to fair (AB-5 No. 205 with AEP-47 No. 114).

Table 10 shows data obtained with five radon progeny monitors from MOL. The overall average for the two exposure periods of the ratio WL_{MOL}/WL, i.e., CF, was 0.96 ± 0.16, which can be rated as very good to excellent, except for one monitor (No. 79), which gave consistently low results.

Table 11 shows data regarding the calibration of two WLM-300 Working Level continuous monitors. They both underestimated the Working Level by 20%

to 35% approximately. The difference in response of the two monitors exposed side by side to the same atmosphere was about 15%.

Table 12 gives data for two RGA-400 continuous Working Level monitors. One of the monitors (RGA No. 014) underestimated WL by more than 20%. The performance of the other monitor during the limited period of operation (four days) was quite good.

SUMMARY AND CONCLUSIONS

From all the radon gas monitors tested, Terradex monitors performed best with a calculated calibration factor CF ~0.92 $\pm$ 0.2. PRIMs using LiF underestimated the radon gas concentration by more than 20%. PRIMs using CaF_2:Dy substantially overestimated the radon gas concentration, i.e., well above 50%. NRPB radon gas monitors also overestimated radon gas concentration ($\leq$30%). The performance of the AB-5/EL and AB-5/PRD systems was only fair, i.e., they overestimated radon gas concentration by more than 20%. The AB-5 No. 208/EL No. 107 did not operate consistently; it showed a steady decrease in response as time increased underestimating the radon concentration considerably after five days of operation. In summary, the performance of Terradex monitors was best, followed by the PRIMs (LiF), the AB-5/EL, and AB-5/PRD systems, and the NRPB monitors. Except for the Terradex and PRIMs (LiF) monitors, the other monitors overestimated, on average, the radon gas concentration.

The alpha-NUCLEAR personal dosimeters (alpha-PRISM) gave fair to very good results when they did not have software or electronic problems, i.e., CF = 0.83 to 0.94.

The MOD-255 radon progeny monitors performed reasonably consistently with an average sensitivity of 2.17 $\pm$ 0.35 nC/WLH or ~0.46 WLH nC^{-1}.

On average, the AB-5/AEP continuous radon progeny monitors

underestimated the Working Level. Their performance can be rated from poor to fair. The MOL radon progeny monitors, on the other hand, performed quite well with a CF close to unity, except for one unit.

The WLM-300 and RGA-400 continuous Working Level monitors, except for the RGA No. 006, underestimated the Working Level by varying amounts. Their performance can be rated from poor to fair. The RGA No. 006 performance can be rated as quite good.

Some of the reasons for the discrepancies observed between data from several instruments and RTTF data have been discussed elsewhere (4-6).

In summary, the overall performance of the instrumentation tested here can only be considered fair. More improvement is necessary in some instrumentation for adequate reliability. Calibration of the nature reported here should be conducted at least twice a year.

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REFERENCES

1. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1982. Ionising Radiation: Sources and Biological Effects. 1982 Report to the General Assembly, United Nations, New York (1982).

2. Bigu, J., "A walk-in radon/thoron test facility"; Am Ind Hyg Assoc J, vol 45, No. 8, pp 525-532; 1984.

3. Bigu, J., "Effect of several radiation control measures for remedial

purposes in a dwelling in the Elliot Lake area"; Division Report M&ET/MRL 86-66(TR), CANMET, Energy, Mines and Resources Canada; 1986.

4. Bigu, J., "Calibration of the Pylon AB-5/AEP system, a continuous radon daughter Working Level monitor"; Division Report M&ET/MRL 86-64(TR), CANMET, Energy, Mines and Resources Canada; 1986.

5. Bigu, J., "Calibration of the Pylon AB-5/EL and AB-5/PRD systems, two continuous radon gas monitors"; Division Report M&ET/MRL 86-65(TR); CANMET, Energy, Mines and Resources Canada; 1986

6. Bigu, J., "Calibration of radon and radon progeny instrumentation of the active and passive type in a large radon (thoron) test facility of the walk-in type"; Division Report M&ET/MRL 86- (TR); 1986.

7. Bigu, J. and Kaldenbach, R., "Theory, operation and performance of a time-integrating, continuous, radon (thoron) daughter Working Level monitor"; Radiat Prot Dosim, vol. 9, pp.19-26; 1984.

8. Bigu, J. and Kaldenbach, R., "A microprocessor-based continuous monitor with alpha-spectroscopy capabilities for the determination of radon, thoron and their progeny"; Radiat Prot Dosim, vol. 12, pp 251-260; 1985.

9. Thomas, J.W. and LeClare, P.C., "A study of the two filter method for radon-222"; Health Physics, vol 18, pp 113-122; 1970.

10. Mayya, Y.S. and Kotrappa, P., "Modified double filter method for the measurement of radon or thoron in air"; Ann Occup Hyg, vol 21, pp 169-176; 1978.

11. Thomas, J.W., "Measurements of radon daughters in air"; Health Physics, vol. 23, pp 783-789; 1972.

12. Kusnetz, H.L., "Radon daughters in mine atmospheres"; Am Ind Hyg Assoc J, vol. 17, p. 1, 1956 (see also Ind Hyg Quarterly, March 1956).

Table 1 - Operating conditions of the RTTF during the instrumentation evaluation period.

Date	$[^{222}Rn]^+$ RM-1003 pCi/L	$[^{222}Rn]^+$ RGM-2 pCi/L	$\overline{WL}$ mWL	T °C	RH %	N^+ cm^{-3}	DR[1]	F[2]	Remarks
March 19/85	40.4	48.1	65.7±2.0	19-21	-	$1.6x10^3$	1:0.26:0.20	0.15	
March 20/85	39.2	46.9	28.4±3.0	20-21	68	$0.6x10^3$	1:0.12:0.08	0.07	
March 21/85	39.1	46.6	32.1±5.0	∿21	50	$1.7x10^3$	1:0.12:0.07	0.07	
March 22/85	38.8	48.0	42.4±3.0	∿21	70	$2.7x10^3$	1:0.18:0.12	0.10	
March 23/85	40.2	46.1	38.2±5.0	-	-	$0.8x10^3$	1:0.16:0.13	0.09	
March 24/85	39.1	46.8	28.2±4.0	-	70	$0.5x10^3$	1:0.11:0.20	0.07	
March 25/85	39.9	49.6	20.0*	∿21	-	$1.0x10^3$	-	∿0.05	
March 26/85	40.7	48.5	64.1±9.0	21-22	70	$3.0x10^3$	1:0.30:0.22	0.14	
March 27/85	39.6	47.9	95.2±5.0	∿21	-	$3.3x10^3$	1:0.39:0.31	0.22	
March 28/85	40.0	46.7	50.9±4.0	21-22	-	$0.5x10^3$	1:0.24:0.18	0.12	
March 29/85	37.1	-	35.9*	22-23	-	$0.5x10^3$	-	∿0.10	

* Calculated from calibrated RGA-400 No. 006.

\+ Daily average.

1 Radon progeny disequilibrium ratios, i.e., $[^{218}Po]/[^{218}Po]$, $[^{214}Pb]/[^{218}Po]$, $[^{214}Po]/[^{218}Po]$. Square brackets indicate activity.

2 F - equilibrium factor defined as the ratio $(WL/[^{222}Rn])x10^2$ where WL is in Working Levels and $[^{222}Rn]$ is in pCi/L.

Table 2 - PRIM radon gas monitor calibration data in the RTTF.
TLD material used was LiF (TLD-700).

Date	PRIM No.	Exposure Time h	TLD-Reading nC	PRIM* pCi/L	$(PRIM)_o$* pCi/L	Sensitivity* $\frac{pCi\ h}{nC\ L}$	$[^{222}Rn]^{+}_{RTTF}$ pCi/L	$\frac{(PRIM)_o}{[^{222}Rn]_{RTTF}}$
March 19-22/85	2648	78	25±2	27	33	103±13	43.39±4.34	0.76
" "	2560	78	31±2	32	44	111±28	43.39±4.34	1.01
" "	2685	78	34±3	43	45	104±7	43.39±4.34	1.04
" "	2508	78	24±2	34	44	142±23	43.39±4.34	1.01
" "	2571	78	18±1	32	32	137±11	43.39±4.34	0.74
" "	2526	78	31±2	34	42	105±14	43.39±4.34	0.97
" "	2627	78	28±2	15	26	72±9	43.39±4.34	0.60
" "	2634	78	25±2	24	27	85±11	43.39±4.34	0.62
" "	2439	78	22±2	21	21	75.7±0.5	43.39±4.34	0.48
" "	2415	78	46±4	32	38	64±6	43.39±4.34	0.88
" "	2438	78	-	-	27	65±1.7	43.39±4.34	0.62
		Ave:	29.40±7.89	34.45±8.57				0.79±0.20

* Data from AECB. PRIM* data obtained from best fitted curve (no forced fit). $(PRIM)_o$* data obtained from forced fit through zero.

+ The radon gas concentration in the RTTF shown above has been obtained by averaging the $[^{222}Rn]$ daily averages for March 19 (44.2 pCi/L), March 20 (43.0 pCi/L), March 21 (42.8 pCi/L), and March 22 (43.4 pCi/L). These values represent, in turn, the daily average values obtained from the RM-1003 and RGM-2.

Table 3 - PRIM radon gas monitor calibration data in the RTTF. TLD material used was CaF_2:Dy.

Date 1985	PRIM No.	Exposure Time h	TLD-Reading nC	PRIM* pCi/L	$[^{222}Rn]_{RTTF}$ pCi/L	$\frac{PRIM}{[^{222}Rn]_{RTTF}}$
March 22-29	2526	163.1	266.2	48	43.27±4.39	1.11
" "	2508	163.1	417.4	75	43.27±4.39	1.73
" "	2571	163.1	297.4	54	43.27±4.39	1.25
" "	2439	163.1	630.7	113	43.27±4.39	2.61
" "	2527	163.1	513.0	92	43.27±4.39	2.13
" "	2634	163.1	285.1	43	43.27±4.39	0.99
			Ave:	70.83±27.65		1.6_{-1}

* Radon gas concentration calculated at AECB.

Note: $[^{222}Rn]_{RTTF}$ shown above represents the average value for the period indicated calculated from the daily averages obtained with the RM-1003 and RGM-2.

Table 4 - NRPB track-etch (CR-39) radon gas monitors calibration data in the RTTF.

Date 1985	NRPB No.	Exposure Time h	$[^{222}Rn]^{*}_{NRPB}$ pCi/L	$[^{222}Rn]_{RTTF}$ pCi/L	$\frac{[^{222}Rn]_{NRPB}}{[^{222}Rn]_{RTTF}}$
March 19-24	165	121.25	44.66	43.27±4.04	1.03
" "	167	121.25	72.04	43.27±4.04	1.66
" "	168	121.25	60.51	43.27±4.04	1.40
" "	169	121.25	73.48	43.27±4.04	1.70
" "	170	121.25	57.63	43.27±4.04	1.33
		Ave:	61.66±11.77		1.42±0.27
March 19-29	163	242.25	60.76	43.30±4.24	1.40
" "	164	242.25	62.21	43.30±4.24	1.44
" "	166	242.25	58.59	43.30±4.24	1.35
" "	172	242.25	54.25	43.30±4.24	1.25
" "	173	242.25	50.64	43.30±4.24	1.17
		Ave:	57.29±4.78		1.32±0.11

* Data by RPB.

Note: $[^{222}Rn]_{RTTF}$ shown above represents the average value for the period indicated calculated from the daily averages obtained with the RM-1003 and RGM-2.

Table 5 - Terradex track-etch radon gas monitors data in the RTTF.

Date 1985	Terradex No.	Exposure Time h	$[^{222}Rn]^{*}_{Tx}$ pCi/L	$[^{222}Rn]_{RTTF}$ pCi/L	$\frac{[^{222}Rn]_{Tx}}{[^{222}Rn]_{RTTF}}$
March 19-24	345302	121.25	56.73	43.27±4.04	1.31
" "	345303	121.25	25.68	43.27±4.04	0.59
" "	345305	121.25	35.49	43.27±4.04	0.82
" "	345309	121.25	45.29	43.27±4.04	1.05
" "	345310	121.25	40.39	43.27±4.04	0.93
		Ave:	40.72±11.52		0.94±0.27
March 19-29	345306	242.25	35.72	43.30±4.24	0.82
" "	345307	242.25	32.25	43.30±4.24	0.74
" "	345308	242.25	48.80	43.30±4.24	1.13
" "	345301	242.25	47.98	43.30±4.24	1.11
" "	345304	242.25	28.37	43.30±4.24	0.65
		Ave:	38.66±9.26		0.89±0.22

* The symbol Tx is used to indicate Terradex. Data supplied by Terradex (U.S.A).

Note: $[^{222}Rn]_{RTTF}$ shown above represents the average value for the period indicated calculated from the daily averages obtained with the RM-1003 and RGM-2.

Table 6 - Data pertaining to the radon gas continuous monitoring systems AB-5/EL and AB-5/PRD in the RTTF.

Date	Monitoring System	$[^{222}Rn]_{AB-5}$ pCi/L	$[^{222}Rn]_{RTTF}$ pCi/L	$\frac{[^{222}Rn]_{AB-5}}{[^{222}Rn]_{RTTF}}$
March 23/85	AB-5 No. 208 and EL No. 107	48.3±3.4	43.1	1.12
March 24/85		50.6±3.7	42.9	1.18
March 25/85		47.5±11.9	44.7	1.06
March 26/85		27.2±4.2	44.6	0.61
March 27/85		20.5±1.5	43.7	0.47
March 21/85	AB-5 No. 202 and EL No. 103	52.6±9.1	42.8	1.23
March 22/85		53.9±2.6	43.4	1.24
March 23/85		52.7±1.7	43.1	1.22
March 24/85		54.6±1.5	42.9	1.27
March 24/85	AB-5 No. 205 and PRD No. 111	54.3±3.8	42.9	1.26
March 25/85		56.8±1.8	44.7	1.27
March 26/85		58.5±6.3	44.6	1.31
March 27/85		60.3±3.3	43.7	1.38

Note: $[^{222}Rn]_{AB-5}$ represents the daily average radon gas concentration measured by the AB-5 and its associated radon gas detector, i.e., EL or PRD.

$[^{222}Rn]_{RTTF}$ is the daily average radon gas concentration measured with the RM-1003 and RGM-2.

Table 7 - alpha-NUCLEAR dosimeters (alpha-PRISM) data in the RTTF.

Date	WL mWL	No. 009 mWL	No. 010 mWL	No. 056 mWL	No. 010 / WL	No. 056 / WL
March 25/85	19.9±0.6*	-	16.7±2.4	18.0±2.0	0.84	0.90
March 26/85	64.1±9.0	-	-	61.6±8.6	-	0.96
March 27/85	95.2±5.0	-	-	97.7±6.7	-	1.03
March 28/85	50.9±4.0	-	42.5±3.9	43.6±4.0	0.83	0.86
March 29/85	35.9±0.1*	-	-	34.3±3.5	-	0.95
				Ave:	0.83	0.94±0.06

* Values obtained from a calibrated RGA-400 (No. 006).

Notes: 1) WL represents grab-sampling measurements by the Thomas method in the RTTF.

2) the symbol mWL refers to the Working Level indicated by the dosimeter.

3) the horizontal bars indicate electronic or software malfunction.

Table 8 - MOD-255 radon progeny data in the RTTF.

Date 1985	MOD-225 No.	Exposure Time h	TLD-Reading nC	WL mWL	WLH	Sensitivity nC/WLH
March 19-22	2908	77.7	5.80	36.4	2.828	2.051
" "	3083	77.7	5.62	36.4	2.828	1.987
" "	0001	77.7	6.82	36.4	2.828	2.411
		Ave:	6.08			2.15
March 19-29	3080	241.4	32.1	48.8	11.78	2.725
" "	3082	241.4	20.5	48.8	11.78	1.740
" "	2897	241.4	24.7	48.8	11.78	2.097
		Ave:				2.19

Note: 1) WL represents grab-sampling measurements by Thomas method, averaged over the corresponding exposure period.

2) WLH stands for (WL) x (exposure time, h).

3) TLD readings provided by AECB.

Table 9 - Data pertaining to the AB-5/AEP Working Level continuous monitoring system.

Date	Monitoring System	WL_{AB-5} mWL	WL mWL	$\frac{WL_{AB-5}}{WL}$
March 26/85	AB-5 No. 202 and AEP-25 No. 106	37.5±6.1	64.1±9.0	0.58
March 27/85		54.3±7.5	95.2±5.0	0.57
March 28/85		31.6±2.5	50.9±4.0	0.62
March 29/85		27.7±1.9	35.9±0.1*	0.77
March 20/85	AB-5 No. 208 and AEP-47 No. 119	17.6±1.6	28.4±3.0	0.62
March 21/85		26.9±3.6	32.1±5.0	0.84
March 22/85		36.1±2.7	42.4±3.0	0.85
March 27/85	AB-5 No. 205 and AEP-47 No. 114	83.7±6.9	95.2±5.0	0.88
March 28/85		48.7±3.4	50.9±4.0	0.96
March 29/85		43.5±3.4	35.9±0.1*	1.21

* Value obtained from a calibrated RGA-400 (No. 006).

Notes: 1) WL_{AB-5} represents the Working Level measured by the AB-5 and its associated sampling head AEP.

2) WL represents grab-sampling measurements, by Thomas method, in the RTTF averaged over the sampling period.

Table 10 - MOL radon progeny monitors data in the RTTF.

Date 1985	MOL No.	Exposure Time h	WL_{MOL} mWL	WL mWL	$\frac{WL_{MOL}}{WL}$
March 19-25	8	142.1	37.0	35.98	1.03
" "	16	142.1	39.0	35.98	1.08
" "	64	142.1	37.0	35.98	1.03
" "	79	142.1	27.0	35.98	0.75
" "	89	142.1	43.0	35.98	1.19
		Ave:	36.6±5.9		1.02±0.16
March 25-29	8	99.6	60.0	63.12	0.95
" "	16	99.7	56.0	63.12	0.89
" "	64	99.6	60.0	63.12	0.95
" "	79	99.7	41.0	63.12	0.65
" "	89	99.7	69.0	63.12	1.09
		Ave:	57.2±10.2		0.91±0.16

Notes: 1) WL_{MOL} represents the Working Level measured by the instrument. Data from M.O.L.

2) WL represents the Working Level, by the Thomas method, in the RTTF averaged over the indicated expcsure period.

Table 11 - Data pertaining to the WLM-300 Working Level continuous monitors in the RTTF.

Date	WLM No. 030 mWL	WLM No. 010 mWL	WL mWL	WLM No. 030 WL	WLM No. 010 WL
March 19/85	30.7	28.7	65.7±2.0	0.48*	0.44*
March 20/85	22.6	20.4	28.4±3.0	0.80	0.72
March 21/85	24.9	21.5	32.1±5.0	0.78	0.67
March 22/85	36.0	31.4	42.4±3.0	0.85	0.74
March 23/85	30.6	27.0	38.2±5.0	0.80	0.71
March 24/85	20.4	18.7	28.2±4.0	0.72	0.66
March 26/85	57.6	49.2	64.1±9.0	0.90	0.77
March 27/85	93.1	75.7	95.2±5.0	0.98	0.79
March 28/85	43.2	37.1	50.9±4.0	0.85	0.73
			Ave:	0.83±0.08	0.72±0.04

* Dirty filters which had to be changed. Results not included in the average calculation.

Note: WL represents the daily average Working Level by the Thomas method in the RTTF.

Table 12 - Data pertaining to the RGA-400 continuous Working Level monitors in the RTTF.

Date	RGA No. 014 mWL	RGA No. 006 mWL	WL mWL	RGA No. 014 / WL	RGA No. 006 / WL
March 19/85	62.8±11.5	N/A	65.7±2.0	0.96	-
March 20/85	18.9±2.2	N/A	28.4±3.0	0.66	-
March 21/85	20.8±3.3	N/A	32.1±5.0	0.65	-
March 23/85	34.7±11.0	N/A	38.2±5.0	0.91	-
March 24/85	20.9±4.0	17.0±1.8	28.2±4.0	0.74	0.81
March 26/95	52.8±8.0	57.2±5.3	64.1±9.0	0.82	1.08
March 27/85	86.1±4.3	88.9±5.4	95.2±5.0	0.90	1.03
March 28/85	40.3±3.4	40.5±2.9	50.9±4.0	0.79	1.00
			Ave:	0.80±0.12	0.98±0.12

Note: WL represents the daily average Working Level by the Thomas method in the RTTF.